DESIGN A HIGH GAIN UWB MIMO UNIPLANAR MONOPOLE ANTENNA WITH FSS ARRAY FOR METALLIC OBJECT MICROWAVE IMAGING

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"To my beloved parents for their praying and supporting. Specially to my lovely wife your praying, supporting, and patience keeps me up alive and my lovely kids".

"To my family, country, the Iraqi government, and all the people for safe life".

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ABSTRACT

Ultra-wideband (UWB) system plays an important role in microwave imaging (MWI) applications due to its broad bandwidth, non-ionising radiation, and cost-efficiency. This study involves the design and development phases for the optimum solution of UWB antenna's issues. In the design phase, a compact uniplanar hexagonal UWB monopole antenna with a coplanar waveguide (CPW) feed is designed. The proposed UWB antenna has an oscillate impedance (*Za*) of 50 Ω. A meander-line notch filter is loaded on the designed antenna that achieves a high rejection (S_{11} = -1.75 dB) at the band of 3.0 GHz for 5G mid-band. A T-strip is inserted between the two proposed MIMO antennas to improve the isolation. Moreover, the smallest uniplanar UWB frequency selective surface (FSS) unit cell size (0.095λ×0.095λ) is miniaturized on the FR4 substrate. The simulations are compared with the equivalent circuit models of the proposed solutions, then validate with the measurement results. In the development phase, the hexagonal monopole MIMO antenna, the CPW feed, the isolation T-strip, and the 3 × 7 FSS array are assembled to develop the MWI. The isolated MIMO antenna with FSS (IMAF) achieves a bandwidth of 3-11.7 GHz, unidirectional radiation patterns, mutual coupling (S_{21} about -27 dB) and gain (6-8.5 dBi), and it better than the existing antennas of 3.1-10.6 GHz, -20 dB, and 5.5 dBi, respectively. Additionally, the baggage–scanner scheme is developed as a case study to evaluate the IMAF for near-field MWI. The evaluated images show a resolution of the IMAF is 55% higher than that of the MIMO antenna without an FSS array. Thus, the proposed IMAF detects the smallest (0.5×2 cm^2) metallic object with a location accuracy of ± 0.5 cm compared with the recent simulation study of (0.6 × 0.6 cm^2 and ±1.1 cm, respectively). A good agreement is observed between the simulated and measured images of the MWI. Consequently, the IMAF is proved to be applicable as part of the detection system for low-cost and non-intricate baggage–scanner imaging to detect metallic objects.

ABSTRAK

Sistem jalurlebar-ultra (UWB) memainkan peranan penting dalam aplikasi pengimejan gelombang mikro (MWI) kerana lebar jalur yang luas, sinaran tak mengion, dan kecekapan kos. Kajian ini melibatkan fasa rekabentuk dan pembangunan untuk penyelesaian optimum masalah antena UWB. Dalam fasa rekabentuk, sebuah antena padat ekakutub UWB heksagon satah sesisi dengan suapan pandu gelombang sesatah (CPW) telah direkabentuk. Antena UWB yang dicadangkan mempunyai galangan berayun (*Za*) sebanyak 50 Ω. Sebuah penapis takuk garisan liku dimuatkan pada antena yang direkabentuk yang mencapai penolakan tinggi (S_{11} = -1.75 dB) pada jalur 3.0 GHz untuk band 5G. Sebuah jalur-T telah dimasukkan di antara dua antena MIMO yang dicadangkan untuk meningkatkan pemencilan. Tambahan lagi, saiz sel unit terkecil permukaan pemilihan frekuensi (FSS) UWB satah sesisi (0.095λ × 0.095λ) telah dipadatkan pada substratum FR4. Simulasi dibandingkan dengan model litar bersamaan bagi penyelesaian yang dicadangkan, kemudian disahkan dengan hasil pengukuran. Dalam fasa pembangunan, antena MIMO ekakutub heksagon, suapan CPW, pemencilan jalut-T, dan 3 × 7 tatasusunan FSS telah dihimpunkan untuk membangunkan MWI. Antena MIMO terpencil dengan FSS (IMAF) mencapai lebar jalur 3-11.7 GHz, corak sinaran searah, gandingan bersama (S_{21} bout -27 dB) dan keuntungan (6-8.5 dBi), dan lebih baik daripada antena sedia ada 3.1-10.6 GHz, -20 dB, and 5.5 dBi, masing-masing. Di samping itu, skima pengimbas bagasi telah dibangunkan sebagai kajian kes untuk menilai IMAF bagi MWI medan berhampiran. Imej yang dinilai menunjukkan resolusi IMAF 55% lebih tinggi daripada antena MIMO tanpa tatasusunan FSS. Oleh itu, IMAF yang dicadangkan mengesan objek logam yang terkecil (0.5 × 2 cm^2) dengan ketepatan lokasi ± 0.5 cm berbanding dengan kajian simulasi baru-baru ini ada (0.6 × 0.6 cm^2 dan ± 1.1 cm). Persetujuan yang baik dipatuhi antara imej MWI yang telah disimulasi dan diukur. Akibatnya, IMAF dibuktikan dapat digunakan sebagai sebahagian daripada sistem pengesanan

untuk pengimejan pengimbas bagasi kos rendah dan tidak rumit bagi mengesan objek logam.

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LIST OF ABBREVIATIONS

2D	-	Two-dimensional
3D	-	Three-dimensional
AMC	-	Artificial magnetic conductor
AND	-	Logic operator
AUT	-	Antenna under test
AVA	-	Antipodal Vivaldi antenna
BiD	-	Bidirectional radiation pattern
BW	-	Bandwidth
CPW	-	Coplanar waveguide feed
CST	-	Computer simulation technology
DG	-	Diversity gain
DGS	-	Defected ground structure
EBG	-	Electromagnetic band-gap
ECC	-	Envelope correlation coefficient
ECM	-	Equivalent circuit model
EM	-	Electromagnetic
EMI	-	Electromagnetic interference
FBW	-	Fractional bandwidth
FCC	-	Federal Communications Commission USA
FIT	-	Finite integration technique
FKEE	-	Faculty of Electrical and Electronic Engineering
FR4	-	Glass-reinforced epoxy laminate material
FSS	-	Frequency selective surface
GPR	-	Ground-penetrating radar
HPBW	-	Half power beamwidth
IEEE	-	Institute of Electrical and Electronics Engineers
IFFT	-	Inverse fast Fourier transform

IMA	-	Isolated UWB MIMO antenna
IMAF	-	Isolated UWB MIMO antenna with FSS array
ISM	-	Industrial, scientific and medical radio band
MATLAB	-	Matrix laboratory software
MIMO	-	Multiple-input and multiple-output
MS Excel	-	Microsoft Excel
MWI	-	Microwave imaging
OD	-	Omnidirectional radiation pattern
OFDM	-	Orthogonal frequency division multiplexing
PCB	-	Printed circuit board
PHMAS	-	Printed hexagonal monopole antenna side-feed
PHMAV	-	Printed hexagonal monopole antenna vertex-feed
PL	-	Path length
RF	-	Radio frequency
RLC	-	Resistor, inductor, and a capacitor resonant circuit
Rx	-	Receiver
SAR	-	Specific absorption rate value
SMA	-	SubMiniature version A 50 ohm connector
SNR	-	Signal-to-noise power ratio
SRR	-	Split ring resonator
STW	-	See-through wall
SVM	-	Support vector machine
TE	-	Transverse electric
Tx	-	Transmitter
UDRP		Unidirectional radiation pattern
UTHM	-	Universiti Tun Hussein Onn Malaysia
UWB	-	Ultra-wideband
VNA	-	Vector network analyzer
VSWR	-	Voltage standing wave ratio
WiMAX	-	Worldwide interoperability for microwave access
WLAN	-	Wireless local area network
WPAN	-	Wireless personal area network

LIST OF SYMBOLS

dB , dBi	-	Logarithmic scale unit, and Isotropic logarithmic scale unit
S_{11}, S_{22}	-	Reflection coefficients
S_{21}, S_{12}	-	Transmission coefficients
cm , cm^2, cm^3	-	Centimeter, square centimeter, cubic centimeter are units
mm, mm^2, mm^3	-	Millimeter, square millimeter, cubic millimeter are units
GHz	-	Gigahertz is unit
MHz	-	Megahertz is unit
Da	-	Distance between the MIMO antenna elements
Dz	-	Distance between the antenna and FSS array
D_o	-	Largest dimension of the antenna
Rd	-	Near-field region
λ	-	Wavelength
λ_o	-	Wavelength of resonance frequency
f , f_o , f_r	-	Resonant frequency
f_c	-	Centre frequency
f_L	-	Lowest frequency
f_H	-	Highest frequency
Ω , nH , pF	-	Ohm, nanohenry, picofarad are units
N	-	Number of articles
ε_r , ε_{reff}	-	Dielectric constant, Effective dielectric constant
L	-	Monopole antenna length
W	-	Monopole antenna width
r	-	Effective radius of the cylindrical monopole antenna
p	-	Gap between the ground plane and the patch
k	-	Constant for the FR4 substrate
Wf	-	Width of the feed line

H	-	Substrate thickness
La , Wa	-	Substrate length and width
S , S_1 , S_2	-	Patch sides length
$a°$	-	Patch sides angle
R	-	The radius of the hexagonal patch
Lf , Wf	-	Feed line length and width
Lg , Wg	-	Ground plane length and width
t	-	Copper patch thickness
Dh	-	Distance between the edge of the patch and the ground plane
$tan\delta$	-	Tangent dielectric loss angle
S_{cpw}	-	Gap between CPW-fed wire and the ground plane
f_{notch} , f_n	-	Notched frequency
L_{slot}	-	Slot's length
ρe	-	Envelope correlation coefficient
π	-	Constant, the ratio of a circle's circumference to diameter
R , L , C	-	Resistor, inductor, and capacitor
Z_o	-	377 Ω free space wave impedance
A_1 and A_2	-	Areas of the ground plane and the radiation patch
Za	-	Antenna impedance
Ls	-	Horizontal length of meander-line strip arms
Lz	-	Vertical length of meander-line strip arms
ths	-	Width of meander-line strip arms
L_{strip}	-	Total length of meander-line strip arms
T_{p1}, T_{p2} , W_{p1}	-	T-strip lengths and width
g_{sp}	-	Gap between the T-strip and the radiator patch
c	-	Speed of light
s	-	Spacing between the metal of FSS unit cells
T_{fsb}	-	Substrate thickness of FSS unit cell
D_x , D_y	-	Physical dimensions width and length of the unit cell
g , L_{fs}	-	Square ring width, Square ring length
W_{fc} , L_{fc}	-	Cross-dipole width, Cross-dipole length
n	-	Constant
$\O$	-	Phase

β	-	Propagation constant of free space
θ	-	Angle of incidence wave on the FSS unit cell
An_{eff}	-	Effective angle of incidence wave on the FSS unit cell
Δx , Δy	-	Step shift of xy scanning plane

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CHAPTER 1

INTRODUCTION

This chapter presents the research motivation, a short background, the problem statement, the objectives, and the scope of this work. Section 1.1 describes the events and the existing technologies that offer significant motivations to carry out this study. The UWB standard and followed by a short background about implementing UWB systems for microwave imaging (MWI) applications are discussed in Section 1.2 and 1.3, respectively. Describing the general problem, several existing issues, and the research direction to fill a gap are elaborated in Section 1.4. The objectives, aim, scope, and the contributions of this study are described in Sections 1.5, 1.6, and 1.7, respectively. Lastly, Section 1.8 briefly reposts the thesis organisation. The details are depicted in the following sections.

1.1 Motivation

Some horrendous events of attacks, such as the September 11 2001 New York City twin towers attack, 2004 Madrid train attack, and 2007 London car bombings, have generated new security adoption processes across the globe. Hence, as a safety measure, the Schiphol airport has begun scanning passengers' body since 2007 [1]. Safeguarding humans from potential attackers have become a top priority. With various cutting-edge approaches devised by attackers to circumvent security inspection, a strong need is present to perform quality security screening in airports and public transportations [2]. While thousands of strangers arrive and depart every single day through airplanes, international airports are the most critical public transportation constrictions. Thus, both international and local airports have been supported by state-of-the-art security systems and devices [2].

Typically, the conventional scanners in airports are X-ray machines. Passengers are required to take-off all their belongings at the security terminal of both local and international airports. The checklist includes wallets, handbags, hats, keys, and phones, to name a few. Next, the belongings are arranged in a plastic box and scanned using the X-ray system machine. Laptops, cans, and containers exceeding 100 ml must be removed from the handbags, and arranged in a box to be scanned by X-ray scanner. This process lengthens the time of loading the luggage bags into the airplane and takes up passengers' time, especially those with short transit trips. Nevertheless, this process is essential because security rules are significant to prevent weapons, such as bombs and handguns, from being carried onto the airplane [3].

Despite the low-resolution display of two-dimensional (2D) images, X-ray poses health risks due to its high ionising radiation towards human tissues [1]. Meanwhile, terahertz radar offers high-resolution images, but its high cost and short distance limit its application at the airports [2].

Airway companies have taken measures by increasing scanner accuracy and time efficiency through enforcement of baggage-screening procedure, but often at the cost of increased waiting time and ticket price [4]. The highlighted concerns had motivated the researcher to develop a modern radar system in the attempt of overcoming these issues that have always remained top security priority. The key solution is by using MWI based UWB system for indoor security purposes [2], which refers to one of the most sought topics in the radar-imaging field. The details of standardisation and regulations of the UWB technology are presented in the next sections.

1.2 UWB standard and regulation

UWB communication uses very narrow RF pulses between the receiver and the transmitter for communication purposes. Short-duration pulses generate extensive bandwidth and have many other advantages, thus are the building blocks for wireless communication. There are many types of waveband signals in a UWB, such as

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